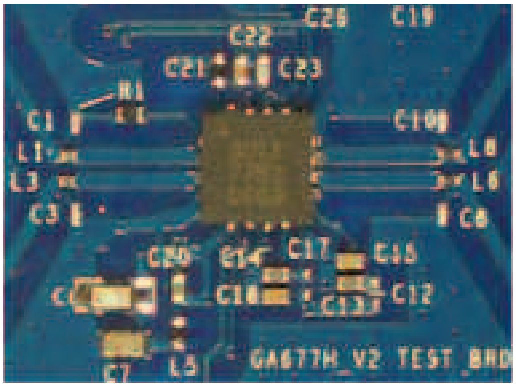
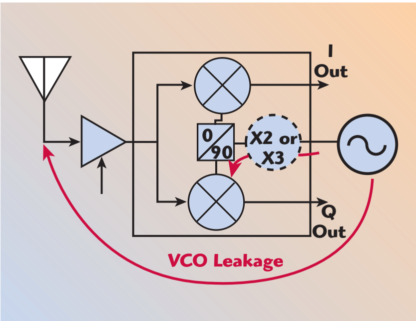


A NEW SOLUTION FOR DIRECT CONVERSION SYSTEM INTEGRATION

Direct conversion radio architectures offer the best compromise between radio performance (adjacent channel rejection and dynamic range), spurious response, versatility (easily allowing multiple modulation bandwidths), current consumption and cost. However, there are several classic issues that must be understood and mitigated before superheterodyne-level performance can be achieved with the convenience of direct conversion. Designed to address these issues is the new SKY73013 direct conversion (and low IF) front-end downconverter IC that enables very high performance operation in the 4.900 to 5.925 GHz frequency spectra.

Fig. 1 The common architecture of the SKY73013 downconverter IC.



In its development, careful attention has been paid to the relevant standards including WiMAX, WLAN and dedicated short-range communication (DSRC), to allow operation of even the most difficult modulation formats, such as 64-QAM OFDM and the stringent WiMAX adjacent channel requirements. Further, this level of intelligent integration in a standard product downconverter enables additional markets such as low cost, low current proprietary wireless data and radio frequency identification (RFID).

LO FREQUENCY PLANNING

The principal issues surrounding direct conversion relate to the fact that the most obvious implementation involves a synthesizer/voltage-controlled oscillator (VCO) that has an integer (or direct) relationship with the carrier frequency. This causes radiation coupling issues that can upset the phase-locked loops (PLL) and create a transient upon T/R (transmit/receive) mode change; transmit phase modulation can injection-pull the VCO; and local oscillator-radio frequency (LO-RF) leakage creates a DC offset that varies with the LO-RF coupling profile (that is, low noise amplifiers gain setting and antenna return loss). ***Figure 1*** shows this common architecture; ***Figure 2*** depicts the potential baseband transient response.

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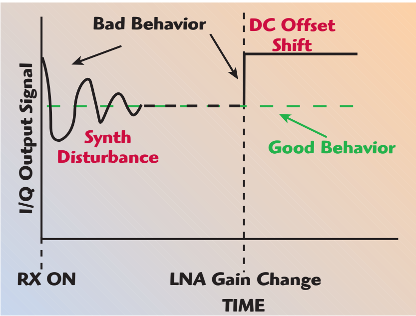
Common strategies, such as shielding and buffering, are usually impractical as their required cost/complexity often outweighs the intended benefits of direct conversion. One should consider that a VCO has an extremely high gain at its resonance frequency, as it is a sensitive radio receiver itself. Therefore, it is quite difficult to fully isolate a VCO, considering that much of the coupling and feedback is radiated rather than conducted. The similar transmitter architecture is even more vulnerable to VCO disturbances.

Another common isolation technique is to operate the VCO/synthesizer at one-half or one-third the carrier frequency, then apply a doubler or tripler in the LO chain, which also increases phase noise at a rate of 6 dB per octave. Although additional isolation is achieved, particularly when the one-half approach is combined with a differential architecture, the challenges still exist, since VCOs are still very susceptible to harmonics and the resultant harmonics still produce dynamic DC offsets.

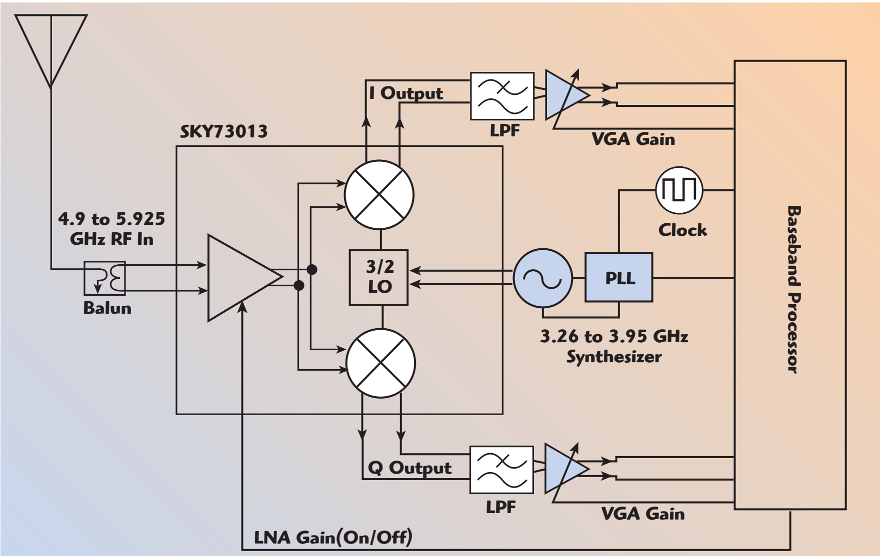


▲ *Fig. 2 Potential baseband transient response.*

Also, the 2X frequency planning technique, where the VCO would operate from 10 to 12 GHz, could be effective for the receiver, though still potentially problematic for the complementary transmitter since the second harmonic of the PA would be synchronous with the VCO. This synthesizer reference requirement, however, would simply be too difficult and expensive to achieve with conventional standard product devices.

In order to overcome such problems the SKY73013 IC utilizes a 3/2 LO architecture where the VCO/synthesizer operates at 2/3 of the carrier frequency. This eliminates VCO radiation pulling problems and dynamic DC offsets (especially important at an LNA gain change), while requiring an LO signal that is well within the frequency range of conventional PCB materials, and off-the-shelf synthesizers and VCOs (3.26 to 3.95 GHz). ***Figure 3*** shows the SKY73013 downconverter's functional block diagram.

The result is that only very high order products could even potentially produce harmonics that are synchronous to the VCO, while dynamic DC offsets are non-existent. This non-integer LO architecture provides a good solution to the conventional direct conversion frequency planning issues without adding to the complexity of the solution.



▲ *Fig. 3 The SKY73013-306 integrated receiver downconverter subsystem for the 4.900 to 5.925 GHz frequency band, featuring 'no-pull' local oscillator architecture and switchable LNA gain.*

QUADRATURE ACCURACY

Additional considerations with direct conversion relate to the fact that the RF signal is demodulated in quadrature, and that phase accuracy and amplitude balance must be maintained over a wide range of frequencies and post-quadrature gain settings, as opposed to splitting to quadrature at a fixed IF. The proprietary 3/2 LO architecture utilized allows extremely accurate quadrature phase/amplitude splitting over a very wide frequency range. Thus, the SKY73013 device produces an I/Q phase accuracy of better than 3° and an amplitude balance of 0.25 dB over the entire operating frequency range and temperature. The system integrator has the option to employ baseband calibration techniques such as I/Q cross-correlation (for phase error canceling) and I/Q averaging (for amplitude balancing) for better performance.

Also, the new downconverter IC, with its 100 MHz I/Q bandwidth, allows low IF image reject operation. This cousin of direct conversion, where the I/Q output is a low frequency IF that is converted to baseband in the digital domain, produces perfect quadrature accuracy at the expense of a higher sampling rate and an analog-domain image product, which is then suppressed by applying a Hilbert transform in the digital domain.

DC OFFSET CORRECTION

A DC offset is almost always present at the output of a mixer and is caused by various RF leakage products. This fact is especially pertinent to direct conversion receiver design because successive stages must be low frequency coupled, since the intermediate frequency is zero. Further, in order to achieve high linearity, which influences adjacent channel performance, it is necessary to place most of the receiver gain after the mixer, rather than before. Therefore, a large amount of DC-coupled post-mixer gain will easily saturate in the presence of an input-referred DC offset.

As long as the DC offset is quasi-static, however, it is possible to remove this offset without degrading communications performance. DC offsets are best mitigated via AC coupling or DC offset subtraction, which are equivalent signal processing operations. Such operations, of course, should not excessively interfere with the in-band signaling content. Therefore, a slow-DC offset correction corner (that is, a low 3 dB high pass in the analog baseband path) should be less than a few percent of the total signaling bandwidth in order to negligibly interfere with the desired information content regardless of whether the modulation is OFDM or single carrier.

Unless the receiver is kept on all of the time, the resultant offset at the output of the mixers is really a step function rather than continuous DC. Therefore, the system integrator should be aware that a slow-DC correction circuit, or AC coupling, requires a finite amount of time to converge. While such convergence periods are acceptable in many communications standards, fast packet switching systems such as WLAN and WiMAX have relatively short T/R turnaround periods. An excellent strategy for these systems is to understand their specific medium access control (MAC) timing intervals such that a fast-settling DC offset initialization loop is enabled during periods where it is not possible to receive data.

In addition, low IF operation offers significant advantages with regards to DC offset correction. Since low IF demodulates the signal with a frequency offset greater than the modulation bandwidth, the entire double-sided signaling spectra appears within both the I and Q arms of the direct conversion output. Therefore, baseband DC offset correction affects frequencies that are above or below the modulation spectra, rather than in the middle. This means that low IF DC correction can always be accomplished with one simple correction loop, while avoiding having to compromise settling time versus signal performance degradation.

DYNAMIC RANGE AND ADJACENT CHANNEL PERFORMANCE

The SKY73013 downconverter IC has been architected to fully support the dynamic range requirements of unlicensed WiMAX and WLAN, which are two very stringent wireless data specifications. In particular, careful attention has been paid to both adjacent and non-adjacent channel performance — the entire chain, including ADCs, must remain linear in the presence of the combination of the desired signal and the adjacent/non-adjacent signal, whose pragmatic peak-to-average ratio approaches 10 dB. The downconverter IC supports sufficient linearity such that packet error rate (PER) requirements are met over the 802.11a and 802.16d (unlicensed 5 GHz OFDM PHY) adjacent/non-adjacent channel conditions.

Non-adjacent channel performance is also dependent upon even-order intermodulation products and many of these products fall about DC. Since direct conversion architectures utilize a zero IF, even-order products become a potential issue. Of particular concern is the fact that this causes an envelope demodulation product of non-adjacent carriers to fall within the IF range. The SKY73013 IC utilizes a differential architecture so even-order intermodulation products are rejected, providing the necessary immunity to envelope demodulation.

The necessary linearity/noise tradeoff was accomplished by properly distributing gain rather than placing a large gain before the mixers, while maintaining enough device gain to overcome even a significant amount of input-referred noise at the baseband VGA inputs. Overall, the downconverter IC is capable of demodulating 64-QAM signals at least as strong as –30 dBm, while maintaining adjacent/non-adjacent channel performance, and has a noise figure of 6.5 dB (high gain mode).

CONCLUSION

The SKY73013 direct conversion front-end downconverter IC has been developed to meet the most stringent standards. This has been achieved by producing a device that is reliable and exhibits high performance at a relatively low cost. Additional information may be obtained via e-mail at sales@skyworksinc.com.

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